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(54) Abstract Title

Apparatus And Method for Producing a Plurality of Coherent Light Outputs

(57) Apparatus for the production of a plurality of coherent light outputs of individually selectable predetermined discrete wavelengths has a first wavelength selectable integrated laser assembly 1, and a second wavelength selectable integrated laser assembly 2. A third laser 3 is capable of generating an output comprising a fixed and predetermined wavelength. A means is used to pass the output of the first and second selectable integrated lasers and the output of the third laser through a medium 4 which allows the outputs from the lasers to interact in a non-linear manner. A filter 6 is used to remove the light at the original wavelengths so to produce an output 7 comprising essentially new generated predetermined discrete wavelengths. The medium 4 may comprise a four wave mixer. The number of wavelengths produced by the apparatus corresponds to the product of the number of wavelengths producible by the two individually selectable lasers. A method of producing a plurality of predetermined selectable discreet wavelengths of coherent light is also disclosed. The new generated predetermined discrete wavelengths may be modulated in response to data a stream 9. In place of the two selectable lasers, there may be three or more selectable lasers (12, 13, 17 see Figure 2), and there may be more than one fixed wavelength laser (33, 37 see Figure 3). Furthermore, the fixed and wavelength laser could be replaced with a multi-wavelength selectable laser. The filter may be a fixed wavelength filter such as a fibre Bragg grating or dielectric stack reflective or transmissive filter.

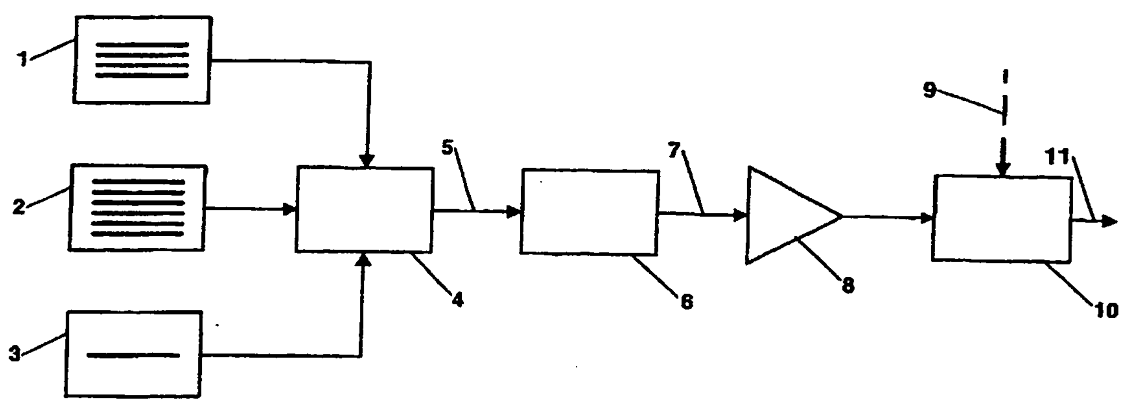

Figure 1.

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The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

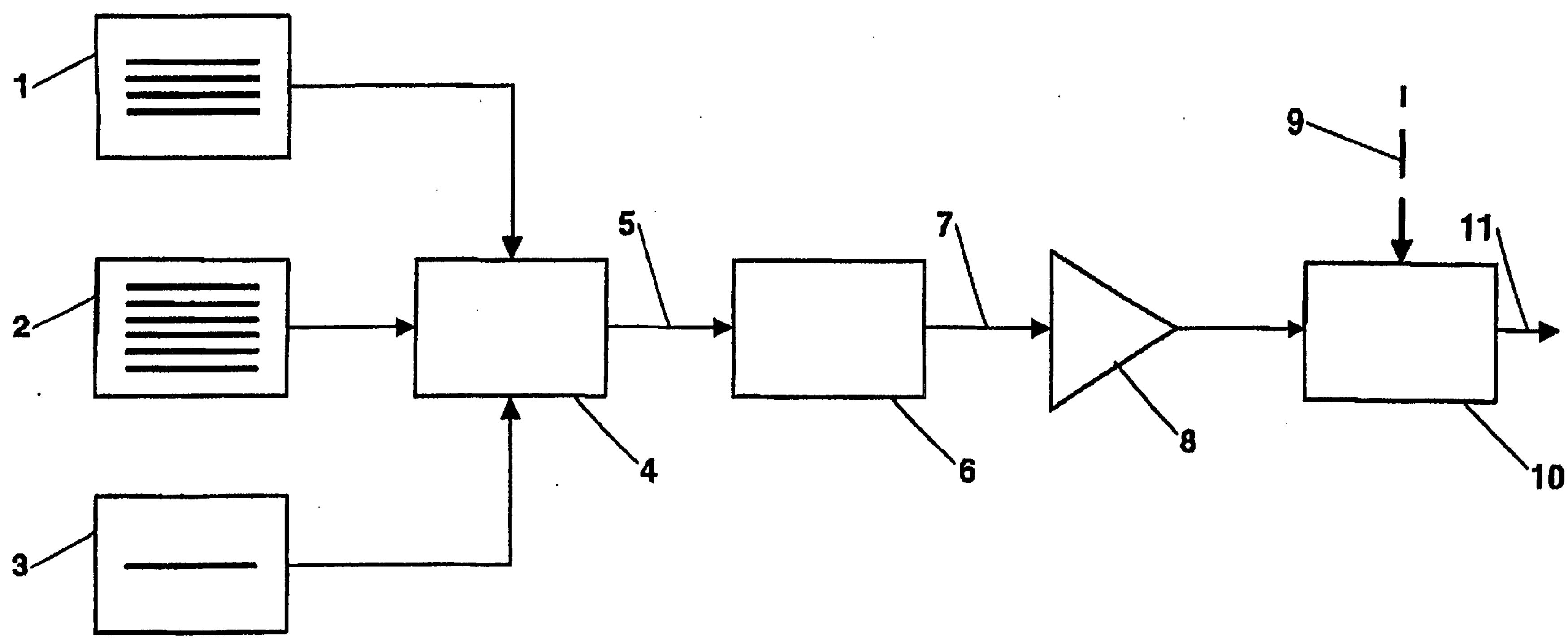

Figure 1.

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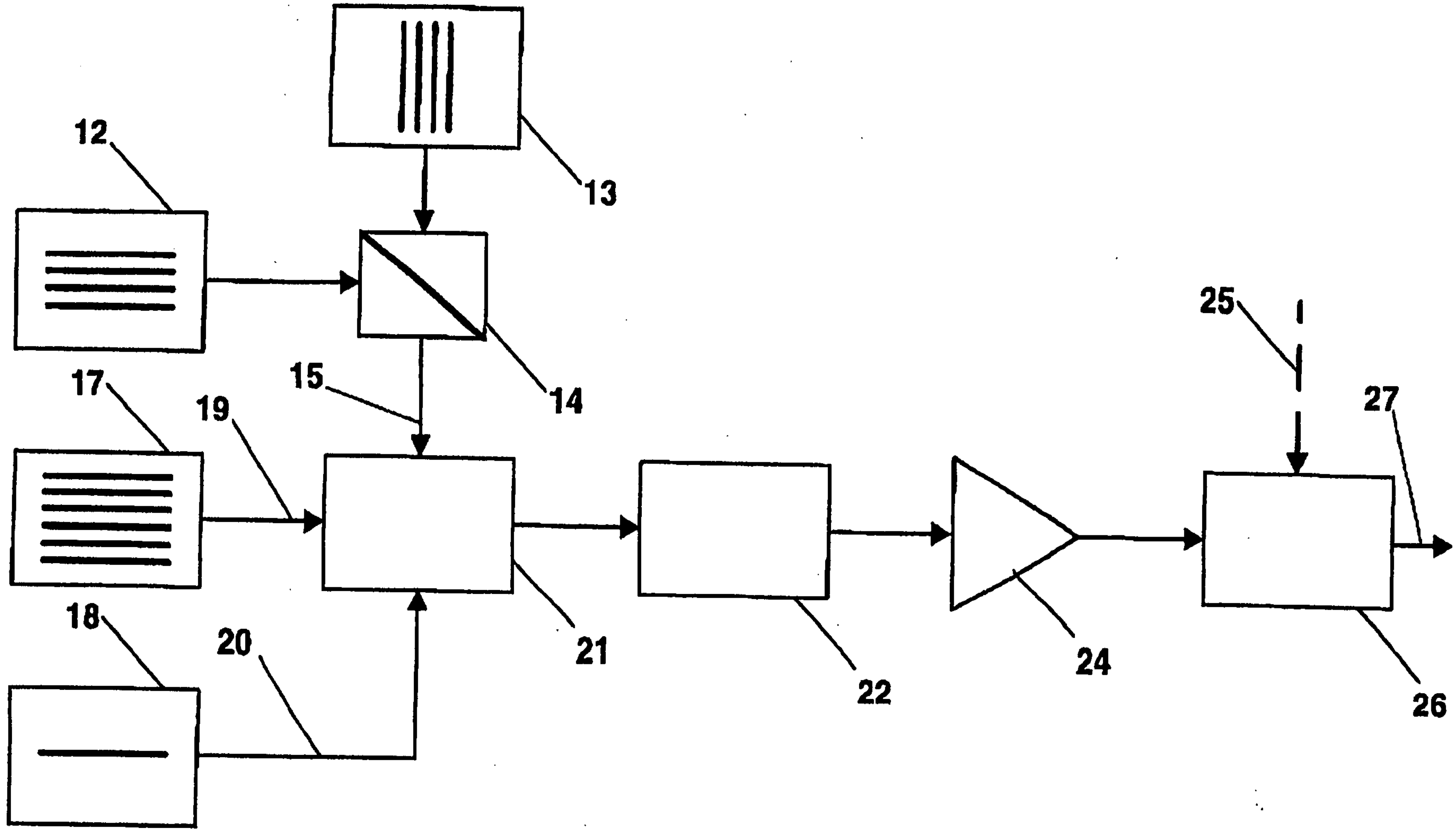

Figure 2.

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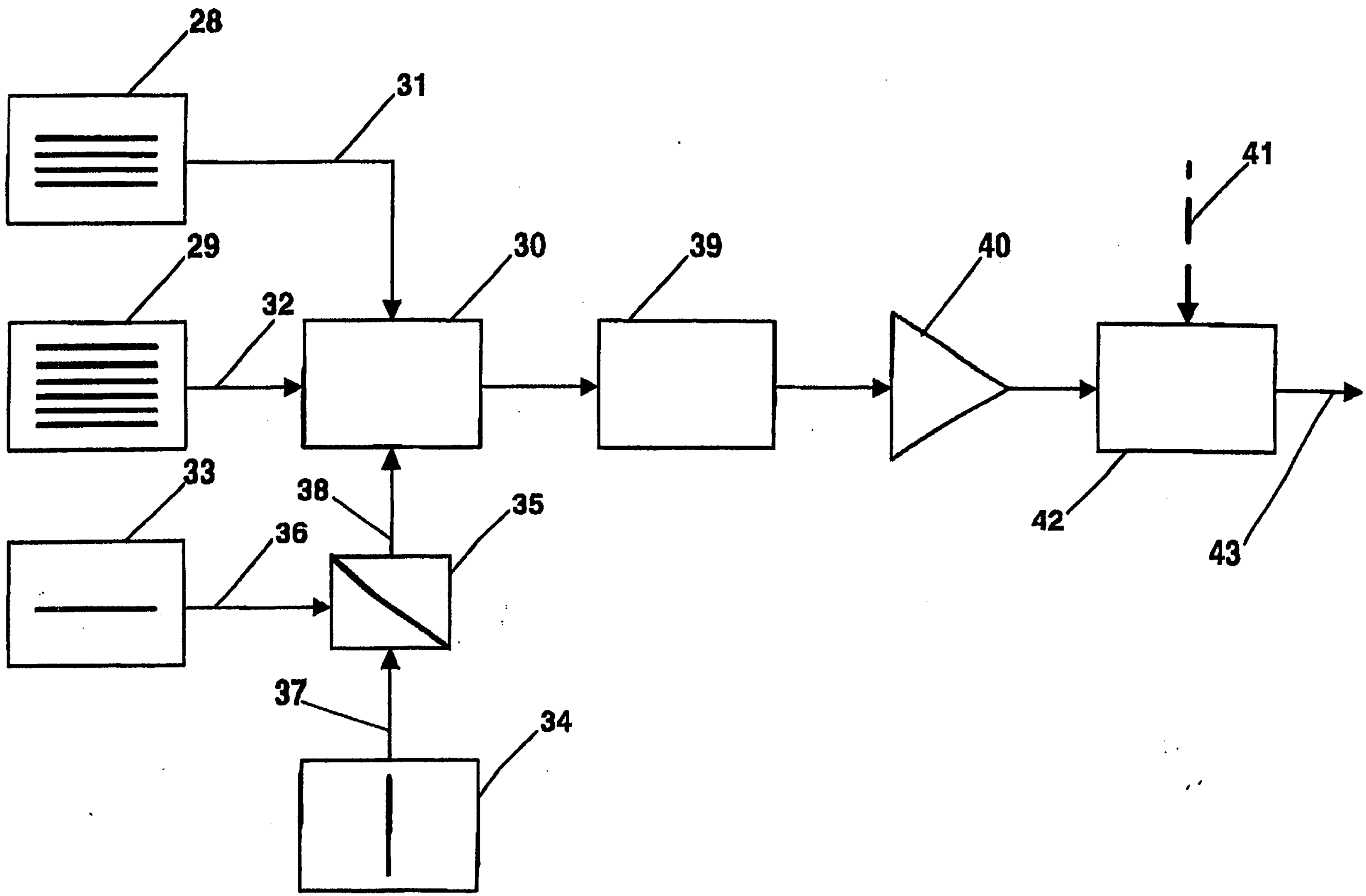

Figure 3.

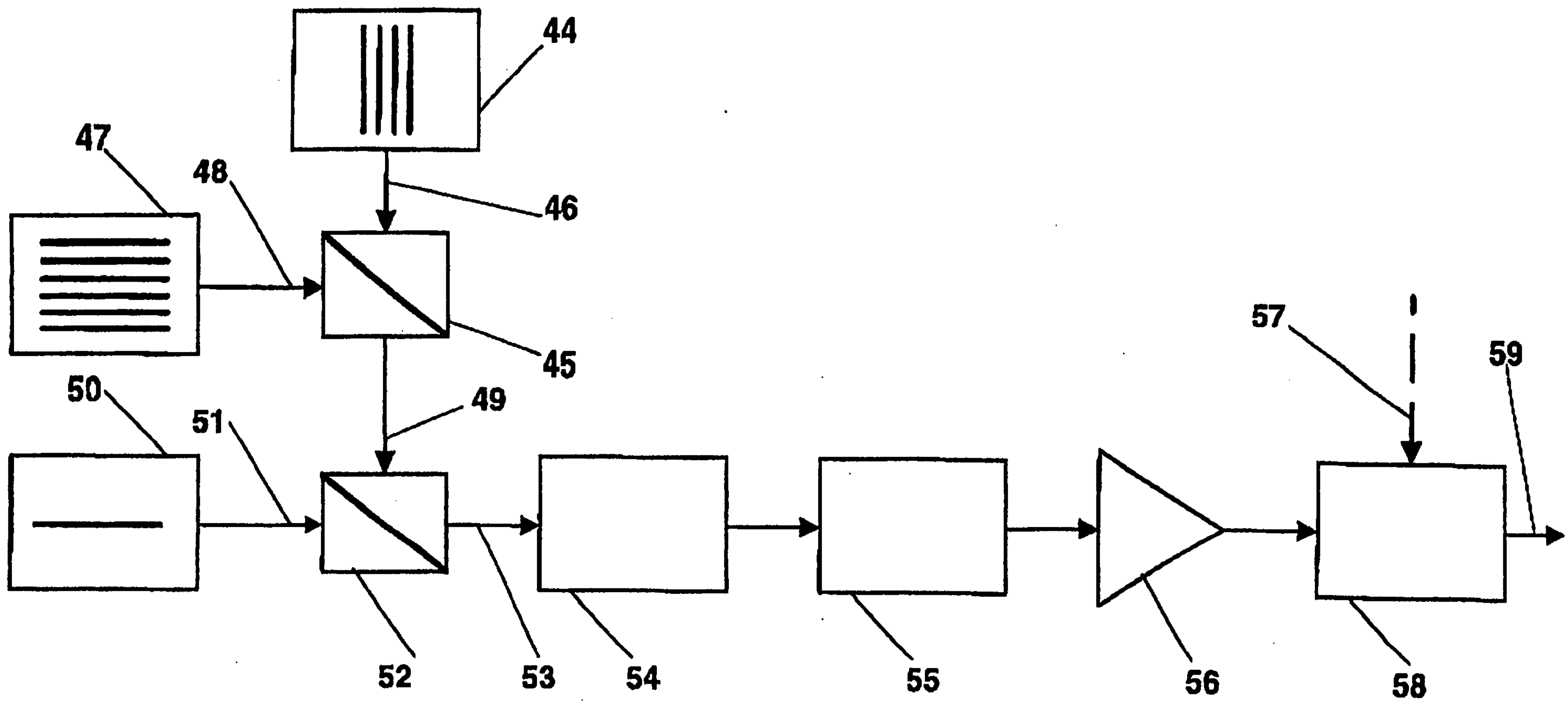

Figure 4.

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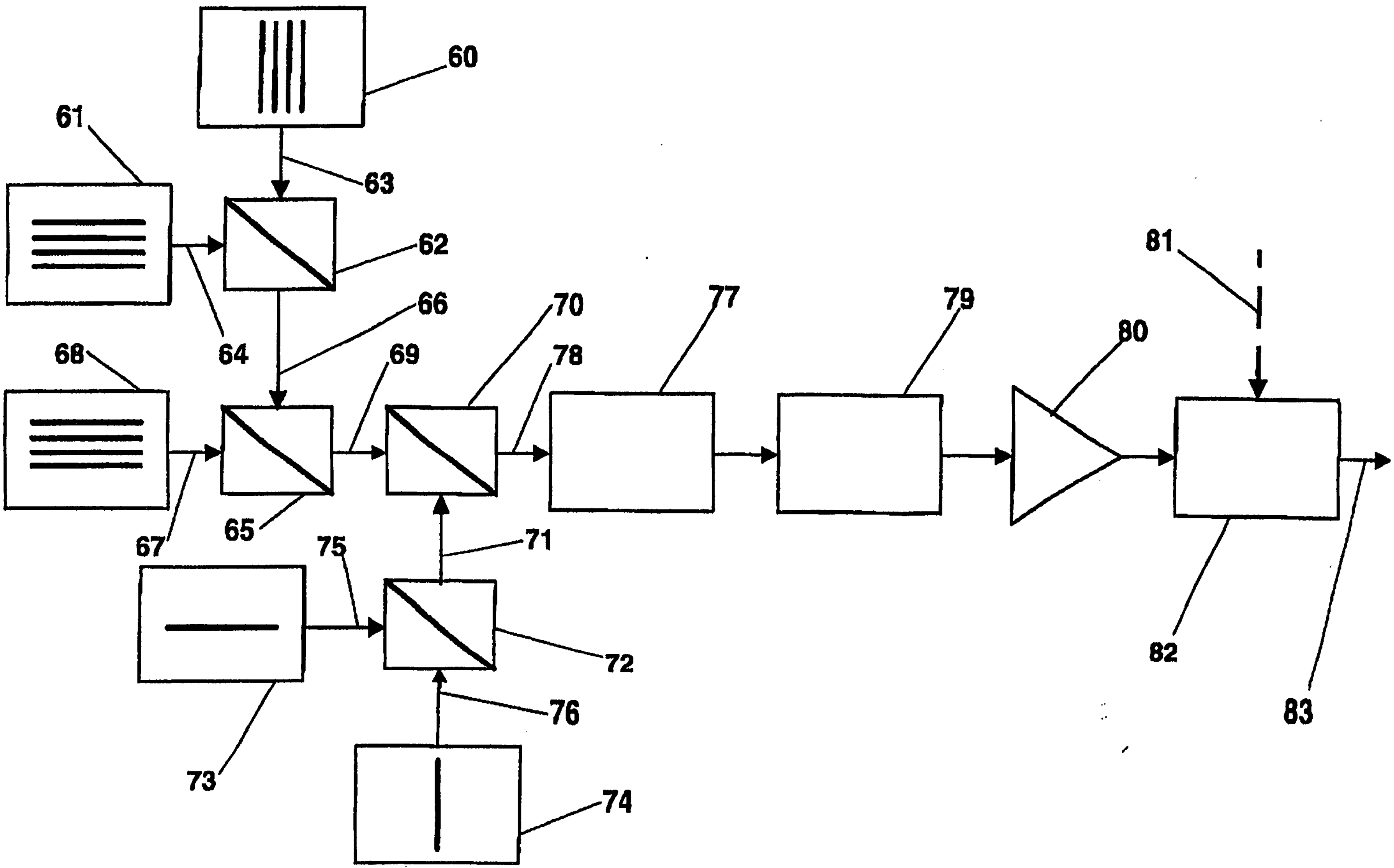

Figure 5.

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TUNEABLE LASER ASSEMBLY AND METHOD

This invention relates to tuneable laser assemblies and methods of producing a plurality of discrete wavelengths of coherent light and has particular, but not necessarily exclusive, reference to laser assemblies intended to form single wavelength outputs for use in the carriage of data.

BACKGROUND TO THE INVENTION

Wavelength routed optical networks offer significant advantages as capacity and flexibility requirements increase. Applying this approach to packet switched networks at high data rates (see for example description of Stanford's HORNET project in Lightwave, July 2000) requires optical transmitters, which can tune over a wide spectrum (several tens of nanometers) in a short time (few nanoseconds).

To be practical and useful the output from the laser must not only be rapidly switchable between wavelengths, but also the wavelengths must be fixed and must not vary, otherwise the wavelength of one signal, if it alters from its nominal wavelength, can interfere with other signals at an adjacent wavelength to the nominal wavelength which are being passed through the same carrier.

One way of producing such a rapidly switchable output is to use a wavelength selectable laser assembly. By combining the outputs from several integrated lasers of different wavelengths into a single output, a single wavelength can be selected quickly. An

experimental laser was used in the UK WASPNET programme (see e.g. WASPNET: A Wavelength Switched Packet Network D. K. Hunter, M. H. M. Nizam, K. M. Guild, J. D. Bainbridge M. C. Chia, A. Tzanakaki, M. F. C. Stephens, R. V. Penty, M. J. O'Mahony, I. Andovic, and I. H. White, IEEE Communications Magazine, p120, Vol. 37 No. 3 Mar. 1999). Advanced samples of 8-channel wavelength selectable lasers are available from NEC. Each wavelength can be continually monitored for error. However, only a limited number of wavelengths can be practically provided, limiting system capacity. Eight or sixteen are currently considered practical numbers.

The problem with this approach is that if the lasers are integrated into a single package then, as the complexity of the package increases, the yield during the manufacturing operation falls, so that there is a practical limit to the number of lasers that can be integrated into a package and be produced at an economic price.

If on the other hand separate lasers are produced, then the practical problems of size and alignment become the limiting factor.

For these reasons the practical limit for the number of wavelengths available by this approach is about eight to sixteen as set out above.

Another alternative solution is to use a distributed feedback laser. A standard DFB (distributed feedback) laser can be thermally tuned, typically by ~0.1nm/C. This has both insufficient range and too slow a response. Sampled grating lasers such as the Marconi Caswell tuneable laser or the vertical coupled laser made by Altitun offer tuning ranges

corresponding to the gain bandwidth of an erbium fibre amplifier, or more. Although tuning between individual pairs of wavelengths may be rapidly effected, especially if current shaping is used to compensate thermal effects, it is in general difficult to arrange fast tuning between all pairs of wavelengths. An account of recent work at the University of California at Santa Barbara can be found in 'Rapid Tuneable Transmitter with Large Number of ITU Channels Accessible in less than 5 ns', by Olga A. Lavrova, Giammarco Rossi and Daniel J. Blumenthal, presented at the European Conference on Optical Communication, Munich in September 2000. Further, known wavelength referencing techniques take time to give an accurate reading and correct errors - too much time for fast packet switching.

The problem has been therefore to provide a rapidly responding laser assembly with a wide range of wavelength outputs which have discrete and predetermined wavelengths, and which do not require wavelength referencing or wavelength policing each time the wavelength is altered.

PROVISIONS OF THE INVENTION

By the present invention there is provided apparatus for the production of a plurality of coherent light outputs of individually selectable predetermined discrete wavelengths which includes:

(i) a first wavelength selectable integrated laser assembly capable of selectively generating a first series of outputs of discrete and predetermined wavelengths of coherent light;

(ii) a second wavelength selectable integrated laser assembly capable of selectively generating a second series of outputs of discrete an d predetermined wavelengths of coherent light;

(iii) the output wavelengths of the first and second laser assemblies being sufficiently close as to be able to interact;

(iv) a medium having a threshold energy value such that at the power density of the coherent light outputs of the first and second laser assemblies the light outputs interact in a non-linear manner;

(v) a third laser capable of generating a output of a fixed and predetermined wavelength;

(vi) means to pass the outputs of the first and second selectable integrated lasers and the third laser as inputs through the medium so as cause an interaction between the two selectable laser outputs and the third laser output within the medium so as to produce an output including the original wavelengths and a new generated predetermined discrete wavelength, and

(vii) means to filter the output to remove the light of the original wavelengths so as to produce an output comprising essentially only the new generated predetermined discrete wavelength,

such that the number of new wavelengths producible by the apparatus corresponds to the product of the number of wavelengths producible by the two individually selectable lasers.

Preferably the filtered output is amplified and the output may be modulated, for example by intensity modulation optionally in response to a data stream. The filter may be a fixed wavelength-blocking filter having wavelength apertures effective at the new wavelengths generated by the interactions.

The wavelengths may be within plus or minus five nanometres for the two selectable lasers and within the range twenty to one hundred nanometres of the two selectable lasers for the third laser.

The outputs may be combined in a four wave mixer. The power ranges for the lasers may be in the range 1 to 1000 milliwatts. The power densities of the interacting lasers within the medium may be in the range 1 to 1000 milliwatts per square micron (mw/@^{2})

The present invention also provides a method of providing a plurality of predetermined selectable discrete wavelengths of coherent light that comprises the steps of inputting into a four wave mixer;

(i) a first input of predetermined wavelength from a first wavelength selectable laser;

(ii) a second input of predetermined wavelength from a second wavelength selectable laser; and

(iii) a third input of a predetermined wavelength from a third laser,

so as to produce an output which includes a new wavelength generated by interaction between the three inputs and passing the combined output through a wavelength blocking filter so as to block out all wavelengths except the new wavelength, whereby the wavelength of the new wavelength can be altered from one discrete predetermined wavelength to another discrete predetermined wavelength by selecting a different output from either or both of the first and second selectable laser.

Preferably the output is amplified and the filter is a static filter.

Although there is described two selectable lasers it will be appreciated that there could be three or more and there may be more than one fixed wavelength laser.

BRIEF DESCRIPTION OF THE DRAWINGS

By way of example a plurality of embodiments of the present invention will now be described with reference to the accompanying drawings, of which: -

Fig 1 is a schematic of a two selectable laser assembly;

Fig 2 is a schematic of an assembly including three selectable lasers and one fixed laser;

Fig 3 is a schematic of an assembly including two selectable lasers and two fixed lasers;

Fig 4 is a schematic of an alternative assembly including two selectable lasers and one fixed laser;

and

Fig 5 is a schematic of an assembly including three selectable lasers and two fixed lasers.

DESCRIPTION OF THE INVENTION

Referring to Fig 1, this shows a first wavelength selectable laser assembly 1, diagrammatically shown as having four lasers each operating at a different wavelength. The individual làsers can be selected for operation extremely rapidly with a switching time of a few nanoseconds. The switching may either be by turning the lasers on and off or by leaving them all on and gating the output, all in a manner well known per se. A suitable selectable laser for such an operation would be an Alcatel 1900 WSL high power

Wavelength Selectable Laser having a power output of up to 10 mw. The wavelength selectable laser 2 is similar except that it has six possible output frequencies but each having the same power output and power density as laser assembly 1.

The third laser 3 is a single output laser of a fixed wavelength. The power output of this laser is less significant than that of lasers 1 and 2. The outputs of lasers 1 and 2 must be sufficiently high so as to enable the outputs to be at a power density when in a non-linear e.g. semiconductor optical amplifier medium (see below) such that they can interact with one another in a non-linear manner A suitable laser is an Alcatel CW DFB laser module, Alcatel 1905 LMI having a power output in the range 1 to 10 mw .

The outputs of the three lasers are input into a four wave mixer 4. For further details of a four wave mixer see the paper by Shen Y R, " Considerations of Four Wave mixing and Dynamic Gratings", IEEE J. of Quantum Mechanics, Vol. QE-22, No 8, August 1986; pages 1196-1203.

A suitable four wave mixer is a semi conductor optical amplifier Alcatel 1901 SOA. Essentially within the four wave mixer there is a medium through which the outputs from the laser pass and at the power density of the laser outputs within the medium the light behaves in a non linear manner to give an interaction between the outputs which results in the generation of a new wavelength in accordance with the formula

$$W_n = W_f+(D(W_{s1},W_{s2}))$$

where W_n is the wavelength of the new generated wavelength, W_f is the wavelength of the fixed output from laser 3, and $D(W_{s1},W_{s2})$ is the difference between the wavelengths of the two selectable laser outputs 1 and 2.

The selectable lasers effectively "beat" with each other in the medium in the four wave mixer and the fixed wavelength laser output interacts with the beat to generate the new wavelength output. This beating will only occur at levels of efficiency that are useful if the two beating frequencies are within a few nanometres of each other, even then the efficiency of generation of the new wavelength is only a few percent of the power input- say 1 to 10 %.

The output of the four wave mixer 4 is thus a mixture of wavelengths including the new generated wavelength and the original input wavelengths. This output is shown schematically at 5.

The output is then passed to a fixed wavelength filter 6 such as a fibre Bragg grating or a die lectric stack reflective or transmissive filter available from JDS-Uniphase. Such a fixed filter differs from a dynamic filter in that the wavelengths filtered cannot be varied. It is best regarded as a filter comprising a plurality of filter apertures at a series of wavelengths that correspond to the newly generated wavelengths. The filter thus blocks all the original wavelengths. Because all three inputs are of discrete and known wavelengths and the new generated wavelength is also fixed and known, the output 7 from the filter is a single new and known wavelength.

Amplifier 8 can then amplify this single wavelength and data 9 may then be modulated onto the laser output at 10, in a manner known per se., so as to produce a modulated laser output 11.

As an example of the number of possibilities of new wavelengths available, if each of the selectable wavelength laser 1 and 2 of Fig 1 had not four and six wavelengths available, but each had only three wavelengths available say at 1500,1503 and 1506 nm for laser 1 and 1497, 1498 and 1499 nm for laser 2 and the wavelength of the laser 3 was 1549 nm, the nine new output wavelengths which could be generated would be as set out in Table 1 below:-

Table 1

Wavelength laser 3	Wavelength laser 1	Wavelength laser 2	Difference	Variable output wavelength
1549nm	1500nm	1499nm	1nm	1550nm
1549nm	1500nm	1498nm	2nm	1551nm
1549nm	1500nm	1497nm	3nm	1552nm
1549nm	1503nm	1499nm	4nm	1553nm
1549nm	1503nm	1498nm	5nm	1554nm
1549nm	1503nm	1497nm	6nm	1555nm
1549nm	1506nm	1499nm	7nm	1556nm
1549nm	1506nm	1498nm	8nm	1557nm
1549nm	1506nm	1497nm	9nm	1558nm

In this case the fixed filter would be required to pass the wavelengths of 1550, 1551, 1552, 1553, 1554, 1555, 1556, 1557 and 1558 nanometres, i.e. nine frequencies in all, and must block the input wavelengths. It does not matter if the filter also passes wavelengths that are not created by the system.

By similar arithmetic the assembly as actually shown in Fig 1 would have 4x6=24 new predetermined wavelengths.

The embodiment of the invention illustrated in Figure 2 enables the invention to produce 96 different new predetermined wavelengths. In this case two selectable lasers 12 and 13 are provided, each having four rapidly selectable wavelengths. The two laser assemblies 12 and 13 have outputs that are input into a half silvered mirror unit 14. This permits either or both of the laser assemblies 12 and 13 to provide an input onto line 15.

A third selectable laser assembly having six rapidly selectable lasers is provided at 17 and a fixed laser 18 similar to laser 3 is also provided. The output of laser assembly 17 and the fixed laser 18 is fed via lines 19 and 20 to a four wave mixer 21, similar to the four wave mixer 4. It will be appreciated that the input through lines 19 and 20 will always be the outputs of lasers 17 and 18. However, because the half silvered unit 14 permits light from either or both laser assemblies 12 and 13 to pass through line 15, it is now possible to select as input for the four wave mixer 21 light from the fixed laser 18 and light from any two of the selectable laser assemblies 12, 13 and 17. From within each of the laser assemblies 12, 13 and 17 it is again possible to select any one of the individually selectable lasers. This means that as only two of the selectable lasers from assemblies 12, 13 and 17 are required to be input into the four wave mixer 21 there is now a possible combination of 4x4x6 selectable lasers i.e. 96 possibilities in all. This means that 96 new wavelengths can be generated by the laser arrangement of Fig 2. In a manner similar to that shown in Figure 1, the output of the four wave mixer 21 is fed to a static filter 22 which blocks the original wavelengths so as to permit only the new wavelength to pass to amplifier 24.

Again the output of the amplifier can be modulated with a signal 25 at 26 in the manner described briefly above to produce a modulated laser output 27.

A half silvered unit may also be used to double the number of single laser units which can be used, as shown in Figure 3. In this embodiment, the two selectable laser units having four and six selectable lasers are shown at 28 and 29. These are each connected to a four wave mixer 30 by lines 31 and 32. Two single laser units 33 and 34 are provided, the output of each of which is connected to a half silvered unit 35 by lines 36 and 37. Lasers 33 and 34 can be selectively operated as required either by switching them on or off or by leaving them on and gating the output. The light from the half silvered unit 35 is passed to the four wave mixer 30 via line 38.

As before, the output of the four wave mixer is filtered by static filter 39, amplified by amplifier 40 and then modulated with data 41 at 42, so as to produce a modulated laser output 43

Figure 4 illustrates how the half silvered mirror units can be assembled to produce an assembly in which the four wave mixing occurs in a semiconductor amplifier medium for example an Alcatel 1901 SOA semi-optical amplifier with a single input position and a single output position.

The output of a selectable laser assembly 44 having four selectable lasers is input into a half silvered unit 45 via a line 46. Similarly the output of a six laser selectable assembly 47 is fed to the half silvered unit via line 48. The combined outputs are fed from the half

silvered unit 45 via line 49. The outputs of the two lasers will not interact in a non-linear manner in the half silvered unit 45 or in the line 49 because the unit and the line are not made of a material have a sufficiently high threshold value at the power densities of the laser outputs in the line 49 and in the half silvered unit 45.

A fixed laser assembly 50 feeds via a line 51 to a half silvered unit 52 where the light combines with the light input into the half silvered unit 52 via line 49 to produce an output on line 53. This is input into the four wave mixer or semi conductor optical amplifier medium 54. The threshold energy values of the half silvered unit 52 and line 53 are such that the light passing through them behaves in a linear manner, but within the medium in the four wave mixer 54 the laser light from lasers 44 and 47 behaves in a non-linear manner to "beat" and thus to generate a new wavelength. The output is again filtered by static filter 55, amplified by amplifier 56, and modulated with signal 57 at 58 so as to produce a modulated signal 59.

The invention also contemplates further extensions of the principal of multiplication of inputs using selectable lasers, both gated and on/off selection being possible.

Figure 5 illustrates an assembly for producing 128 new laser wavelengths of predetermined wavelength in a rapid and predetermined manner. In this arrangement the selectable outputs from selectable laser assemblies 60 and 61 are fed to a half silvered unit 62 by lines 63 and 64. The output from the unit 62 is fed to a further half silvered unit 65 via line 66. Also fed into half silvered unit 65 via line 67 is the selectable output of laser assembly 68 which has four selectable lasers, as do assemblies 60 and 61. The output from the half

silvered unit 65 is fed via line 69 to a further half silvered unit 70, where it is combined with light entering the half silvered unit 70 from line 71. Line 71 interconnects the half silvered unit 70 with the half silvered unit 72. The inputs to the half silvered unit 72 are from the single lasers 73 and 74 via lines 75 and 76. The lasers 73 and 74 can be switched on or off as required and /or the lasers can be left permanently on and have their output gated (so as to have an output or no output from a permanently switched on laser).

The output from the half silvered unit 70 is then passed to the four wave mixing unit 77 via line 78 and then processed through the four wave mixing unit 77, the static filter 79, the amplifier 80 and signal 81 is modulated onto the light at 82 to produce a modulated output 83.

In a yet further embodiment the lasers 73 and 74 could also be replaced with multi wavelength selectable lasers to increase the number of options still further.

Part or all of the assembly of the invention could be monolithically or hybridly integrated.

It will be appreciated that the invention provides a number of distinct advantages. Because the relationship between the input wavelengths and the new generated wavelengths is fixed, as long as the wavelengths of the originating lasers such as lasers 1,2 and 3 are fixed then the output cannot vary in wavelength. This means that no wavelength referencing or policing is required for the output, even though a large number of new wavelengths are possible from a single embodiment of the invention. All of the advantages of a selectable laser assembly are obtained but with a very significant multiplication of available

wavelengths. The components may be made with high yield factors to enable the invention to be produced economically.

By using a static filter rather than a dynamic filter, costs are reduced, the operating switching speeds are increased and there is no danger of wavelength variation in the output. The static filter can have apertures at wavelengths other than those generated by the principal lasers without harm, and this again reduces costs.

It will be appreciated that the static filter may have apertures in regions where such apertures are of no significance. For example there may be very weak and wavelength remote harmonics generated in the four wave mixer, but if they are so low in energy and/or so remote in frequency from the useful frequencies as to be of no concern it would not, in practise, matter if the filter let them through.

It will be appreciated therefore that many embodiments of the invention can be produced to gain the advantage of the invention.

CLAIMS

1. Apparatus for the production of a plurality of coherent light outputs of individually selectable predetermined discrete wavelengths which includes:

(i) a first wavelength selectable integrated laser assembly capable of selectively generating a first series of outputs of discrete and predetermined wavelengths of coherent light;

(ii) a second wavelength selectable integrated laser assembly capable of selectively generating a second series of outputs of discrete and predetermined wavelengths of coherent light;

(iii) the output frequencies of the first and second laser assemblies being sufficiently close as to be able to interact;

(iv) a medium having a threshold energy value such that, at the power density of the coherent light outputs of the first and second laser assemblies, the light outputs interact in a non-linear manner;

(v) a third laser capable of generating an output comprising a fixed and predetermined wavelength;

(vi) means to pass the output of the first and second selectable integrated lasers and the output of the third laser through the medium so as cause an interaction between the two selectable laser outputs and the third laser output to produce an output including the original frequencies and a new generated predetermined discrete wavelength;

(vii) means to filter the output to remove the light of the original wavelengths so as to produce an output comprising essentially the new generated predetermined discrete wavelength,

such that the number of new wavelengths producible by the apparatus corresponds to the product of the number of wavelengths producible by the two individually selectable lasers.

2. Apparatus as in claim 1 in which there is provided means to amplify the filtered output.

3. Apparatus as claimed in claim 1 or 2 in which there is provided means to modulate the output of the new generated wavelength.

4. Apparatus as claimed in claim 3 in which the modulation is of the intensity of the output.

5. Apparatus as claimed in claim 3 or 4 in which the output is modulated in response to a data stream.

6. Apparatus as claimed in any one of claims 1 to 5 in which the means to filter the output comprises a fixed wavelength blocking filter having only wavelength apertures effective at the new wavelengths which can be generated by the interaction.

7. Apparatus as claimed in any one of claims 1 to 6 in which the wavelength of the first series of outputs is within plus or minus five nanometres of the second series.

8. Apparatus as claimed in claim 7 in which the output of the third laser is within 20 to 100 nanometres of the maximum and minimum output wavelength of the first and second selectable lasers.

9. Apparatus as claimed in any one of claims 1 to 8 in which the outputs of the selectable lasers and the fixed laser combine in a four wave filter.

10. A method of providing a plurality of predetermined selectable discrete wavelengths of coherent light that comprises the steps of inputting into a four wave mixer;

(i) a first input of predetermined wavelength from a first wavelength selectable laser

(ii) a second input of predetermined wavelength from a second wavelength selectable laser, and

(iii) a third input of a predetermined wavelength from a third laser

so as to produce an output which includes a new wavelength generated by interaction between the three inputs and passing the combined output through a wavelength blocking filter so as to block out all wavelengths except the new wavelength, whereby the wavelength of the new wavelength can be altered from one discrete predetermined wavelength to another discrete predetermined wavelength by selecting a different output from either or both of the first and second selectable laser.

11. A method as claimed in claim 10 in which the output from the filter is amplified.

12. A method as claimed in claim 10 or 11 in which the filter is a static filter.

13. A method as claimed in claim10 in which the wavelengths of the selectable lasers are within ten nanometers of each other.

14. A method as claimed in claim13 in which the wavelength of the third laser is no more that 150 nanometres from that of the other two lasers.

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INVESTOR IN PEOPLE

Application No:	GB 0107650.4	**Examiner:**	Claire Williams
Claims searched:	ALL	**Date of search:**	24 January 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): H1C (CA, CCX, CEX, CX)

Int Cl (Ed.7): G02F (1/35) H01S (3/00,3/10, 3/13, 3/23,5/40, 5/068, 5/0687)

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	EP 0981189 A2 (Fujitsu) in particular, see column 9 lines 31 to 36.	Y: 2, 3, 5, 6
X,Y	US 4058739 (Bjorkholm et al) whole document	X: 1, 9, 10, 12 Y: 2, 3, 5,6

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		